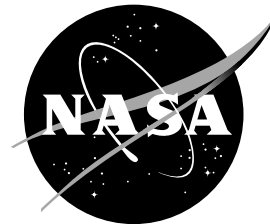


# NASA Facts

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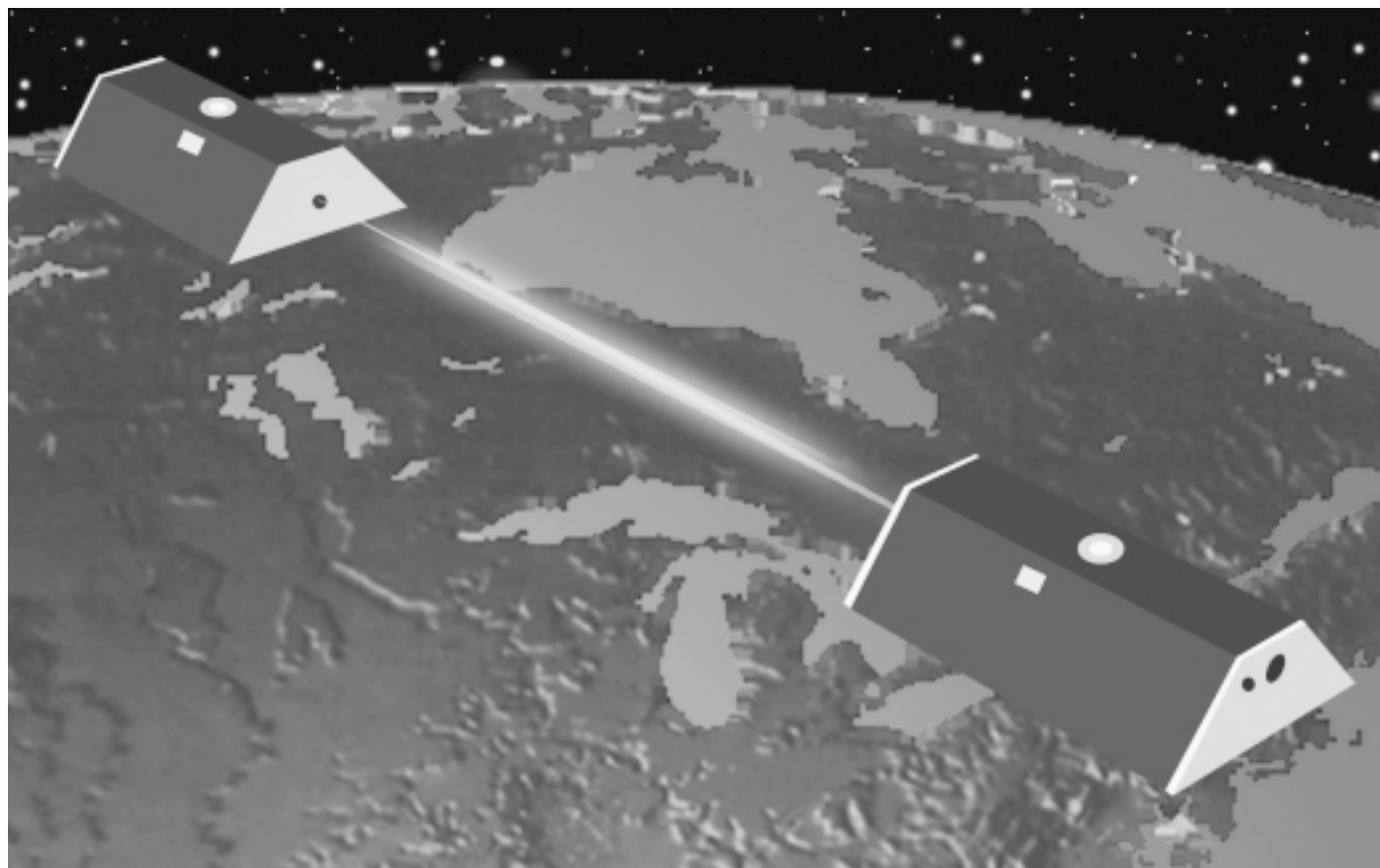
## **The Earth System Science Pathfinder Series**

*These articles discuss the missions and science priorities of the ESSP Program*

*The ESSP Program: <http://essp.gsfc.nasa.gov>*

*The GRACE Mission: <http://www.csr.utexas.edu/grace/>*

# **GRACE: The Gravity Recovery And Climate Experiment**



*GRACE satellites orbiting over the surface of Earth. A K-band microwave link "connects" the two satellites and makes extremely precise (down to the width of a human hair) measurements of the changes in distance between the two satellites. These fluctuations in distance are caused by changes in the orbital motion of the twin spacecraft as they respond to changes in the density of the surface they are passing over. Density changes correspond directly to changes in the force exerted by gravity and can thus be used to produce a map of the gravitational field.*

## Introduction

Gravity! What is it? You can't see it! You can't smell it! You can't touch it! But it's there. In fact, it's everywhere. While the force of gravity is weak compared with other basic forces in nature, such as magnetism and electricity, its effects are the most far-reaching and dramatic. Gravity controls everything from the motion of the ocean tides to the expansion of the entire universe.

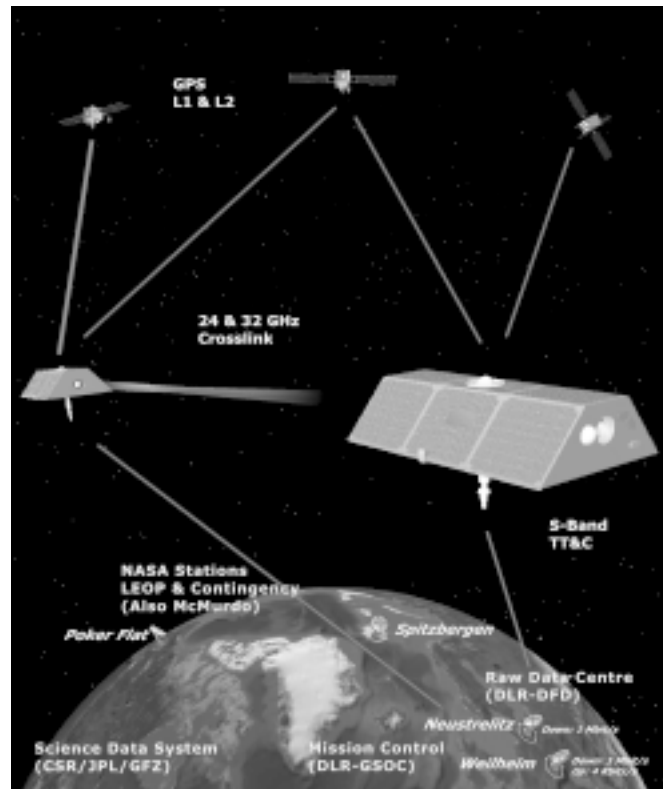
To learn more about the mysteries of gravity, twin satellites named GRACE—short for the Gravity Recovery And Climate Experiment—are being launched to make detailed measurements of Earth's gravity field. This experiment could lead to discoveries about gravity and Earth's natural systems, which could have far-reaching benefits to society and the world's population. More specifically, it is expected that quite a number of disciplines that study aspects of the Earth's changing climate will gain substantial benefits from data retrieved by GRACE.

## The ESSP Program

The GRACE mission will be the inaugural flight of NASA's Earth System Science Pathfinder Program (ESSP). A component of NASA's Earth Science Enterprise (ESE), ESSP missions are intended to address unique, specific, highly focused scientific issues and provide measurements required to support Earth science research. The ESSP missions are an integral part of a dynamic and versatile program consisting of multiple Earth system science space flights. The ESSP program is characterized by relatively low to moderate cost, small- to medium-sized missions that are capable of being built, tested and launched in short-time intervals. These missions are capable of supporting a variety of scientific objectives related to Earth science, including the atmosphere, oceans, land surface, polar ice regions and solid Earth. Investigations include development and operation of remote sensing instruments and conducting research using data returned from these missions. Subsequent satellite launches are planned over the next few years, all of them focusing on the atmospheric sciences.

## GRACE 2002: A Scientific Geodesy

Gravity is the invisible force that pulls two masses together. The branch of science dealing with obtaining precise measurements of the Earth, mapping points on the surface, and studying its gravitational field, is known as *geodesy*. Producing a precise model of the fluctuations in gravity over the Earth's surface has proven to be a formidable task. Currently, data from several dozen satellites must be combined to produce a model of Earth's gravitational field. These models do a good job at simulating the large-scale features of



*A summary of the flight configuration and ground support for the GRACE mission is illustrated here. Fluctuations in density of the Earth's surface result in very small changes in the distance between the two satellites, which are measured with very high precision by the K-band ranging system. The S-band relay (shown protruding from the bottom of each satellite) allows for communication with surface tracking stations. The GPS satellites are used as references to determine the precise location of the two satellites in orbit. The precise positioning information they supply will allow for the creation of gravity maps—approximately once per month.*

Earth's gravitational field but cannot resolve finer-scale features or accurately describe the small month-to-month variations in the gravity field associated with the hydrologic cycle. The unique design of the GRACE mission (twin satellites flying in formation) is expected to lead to an improvement of several orders of magnitude in these gravity measurements and allow much improved resolution of the broad- to finer-scale features of Earth's gravitational field over both land and sea.

The distribution of mass over the Earth is nonuniform. GRACE will determine this uneven mass distribution by measuring changes in Earth's gravity field. The term *mass* refers to the amount of substance in a given space, and is directly correlated to the density of that substance. For example, a container filled with a more dense material, like granite rock, has more mass than that same container filled with water. Because mass and density are

directly related, there is also a direct relationship between density and gravity. An increase in density results in an increase in mass, and an increase in mass results in an increase in the gravitational force exerted by an object. Density fluctuations on the surface of the Earth and in the underlying mantle are thus reflected in variations in the gravity field.

As the GRACE twins fly in formation over the Earth, the precise speed of each satellite and the distance between them is constantly communicated via a microwave K-band ranging instrument. The uniquely designed Superstar Accelerometer on board each spacecraft is used to separate out the effects of nongravitational forces. As the gravitational field changes beneath the satellites—correlating to changes in density of the surface beneath—the orbital motion of each satellite is changed. This change in orbital motion causes the distance between the satellites to change infinitesimally and the K-band can detect these changes, with a resolution of 10 micrometers—the width of a human hair! These data can then be combined with Global Positioning Satellite (GPS) data to produce monthly maps of Earth's gravitational field.

GRACE will do more than just produce a more accurate gravitational field plot. The measurements from GRACE have important implications for improving the accuracy of many scientific measurements related to climate change. Improvements to the accuracy of satellite altimetry, synthetic aperture radar interferometry, and digital terrain models covering large land and ice areas—used in remote sensing applications and cartography—are expected to result from the improved gravitational field measurements provided by GRACE. These techniques provide critical input to many scientific models used in oceanography, hydrology, geology and related disciplines and, for this reason, the Earth science community eagerly anticipates the GRACE launch. Among the expected applications:

- tracking water movement on and beneath Earth's surface;
- tracking the movement and changes in ice sheets and changes in global sea level;
- studying ocean currents both near the surface and far beneath the waves; and
- tracking changes in the structure of the solid Earth.

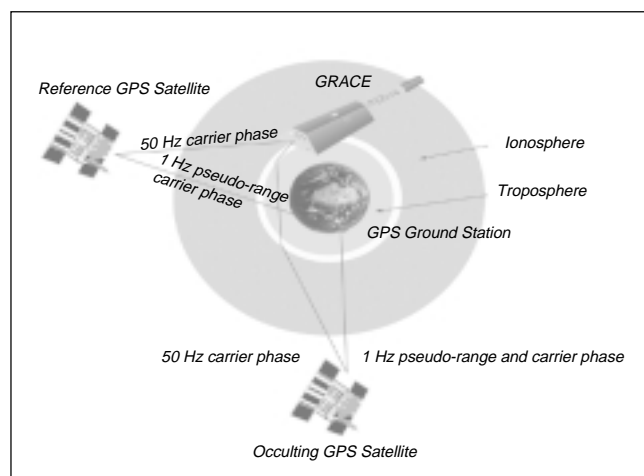
In addition to the primary gravity measurement, the two GPS receivers on GRACE will be used to scan the Earth's limb and determine how much error is introduced into GPS measurements as the GPS signal passes through the atmosphere. This is done using a technique

known as *occultation*, where the GPS receivers track refracted signals from the GPS satellites as they rise or set through the Earth's atmosphere and compare them to a nonocculting GPS satellite. Improvements to the accuracy of GPS measurements expected to result from these measurements will in turn improve the accuracy of soundings of key atmospheric parameters that serve as input for weather prediction models.

### Launch

GRACE will be launched from the Plesetsk Cosmodrome, a former Intercontinental Ballistic Missile (ICBM) site in northern Russia. This site has been one of the most active launch sites in the entire world. EurROCKOT GmbH is providing the launch vehicle. The booster unit is an adaptation of the highly reliable SS-19 ICBM tested in flight over 140 times. A newly developed multi-ignitable and highly maneuverable third stage BREEZE was added. The complete ROCKOT system including BREEZE has been proven in flight three times with a 100% success rate. The payload is assembled on site at Plesetsk and then transported to a launch pad that has been modified to accommodate the ROCKOT launch vehicle. Plesetsk also provides telemetry and tracking services via the existing ground measurement infrastructure.

The two GRACE spacecraft will fly in coplanar orbits between 186 and 310 miles (300 and 500 km) above the surface at an inclination between 89 and 90 degrees. They will be separated along track by between 62 and 310 miles (100 and 500 km)—distance varies over the life of the mission. Orbit maneuvers will be required every 30–60 days in order to maintain the separation between the satellites in addition to occasional calibration and altitude “make-up” maneuvers. The mission is designed for a 5-year lifetime.



The occultation process. The GRACE satellite tracks a GPS satellite as it “rises” and “sets” through the limb of the atmosphere, while a second GPS serves as a reference point.

## Key Spacecraft Components

K-band Ranging System. Provides precise (within 10  $\mu\text{m}$ ) measurements of the distance change between the two satellites and thus measures the fluctuations in gravity.

Ultra Stable Oscillator. Provides frequency generation for the K-band ranging system.

S-band Boom. Allows the satellite to transmit and receive data from surface tracking stations.

SuperSTAR Accelerometers. Precisely measure the nongravitational accelerations acting on the satellite.

Star Camera Assembly. Precisely determines two satellites' orientation by tracking them relative to the position of the stars.

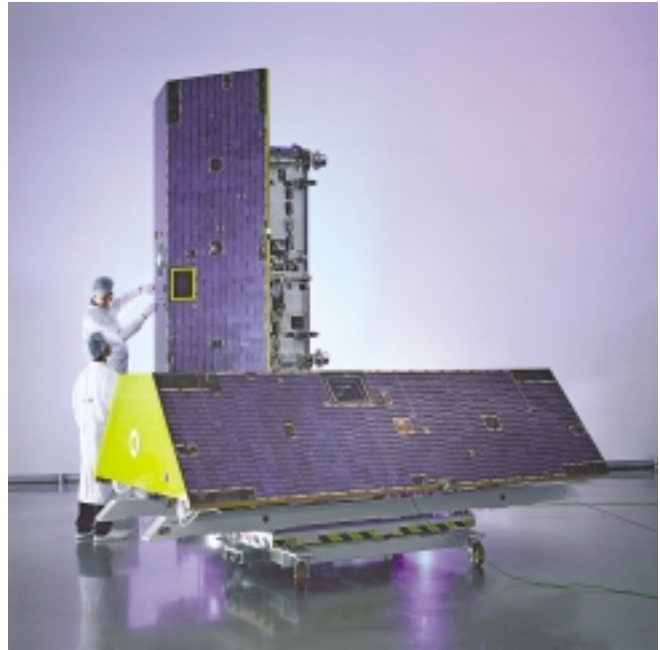
Coarse Earth and Sun Sensor. Provides omnidirectional, reliable and robust, but fairly coarse Earth and Sun tracking. To be used during initial acquisition and when GRACE is operating in "safe mode."

Center of Mass Trim Assembly. Precisely measures offset between the satellite's center of mass and the "acceleration-proof" mass and adjusts center of mass as needed during flight.

Black-Jack GPS Receiver and Instrument Processing Unit. Provides digital signal processing; measures the distance change relative to the GPS satellite constellation; and provides secondary atmospheric occultation experiments.



*A sneak peak at the innards of a spacecraft! For the GRACE mission, the spacecraft themselves are the main instruments.*



*The two identical spacecraft in the environmental test facility at IABG in Ottobrun, Germany. Photo credit: Astrium GmbH.*

Laser Retro-Reflective Assembly. Provides measurements of the GRACE satellite orbits relative to terrestrial tracking networks.

Globalstar Silicon Solar Cell Arrays. Cover the outer shell of the spacecraft and generate power.

Three-axis Stabilized Attitude Control System. Uses star camera and gyro sensors and a cold-gas nitrogen thruster system, with magnetorquers for fine corrections of spacecraft position.

1750-A Microprocessor for Flight Computer. Performs calculations for attitude adjustment and telemetry processing.

## Key Spacecraft Systems

The GRACE Project is divided into the following five systems:

Satellite System (SAT). Jet Propulsion Laboratory (JPL) leads the development of the Satellite System in partnership with Space Systems/Loral (SS/L) and Astrium GmbH (AGmbH). Engineers at JPL developed the GPS receiver and the laser retro-reflective assembly. AGmbH provides major elements of the two satellites based on an existing small satellite designed for the Challenging Minisatellite Payload (CHAMP) mission. SS/L provides the attitude control system, microwave instrument electronics and system and environmental testing.



Science Instrument System (SIS). The SIS is managed by JPL and includes all elements of the intersatellite ranging system, the GPS receivers, and associated sensors such as the star cameras and accelerometers. This system also coordinates the integration activities of all sensors, assuring their compatibility with each other and the satellite.

Launch Vehicle System (LVS). The LVS includes the three-stage ROCKOT launch vehicle, multisatellite dispenser, and the personnel, test equipment and facilities for preparation, integration and launch of the satellites. The LVS is managed by the Launch Vehicle System Manager at Deutsches Zentrum für Luft und Raumfahrt (DLR) and supported by the JPL Project and its contractors.

Mission Operations System (MOS). The MOS consists of facilities and resources of the German Space Operations Center (GSOC), tracking antennas at Weilheim and Neustrelitz, and other stations and facilities needed for supporting launch and early orbit procedures and contingency operations. These facilities are used to monitor and control the satellite, perform initial processing of the telemetry data, and deliver all data to the SDS for further processing and generating science products. In addition to real-time operations, the MOS function provides the Central Checkout System for ground testing using command and data interfaces. The operations team also monitors satellite performance and health throughout the duration of the mission. Mission operations are conducted at the GSOC control center in Oberpfaffenhofen, Germany.

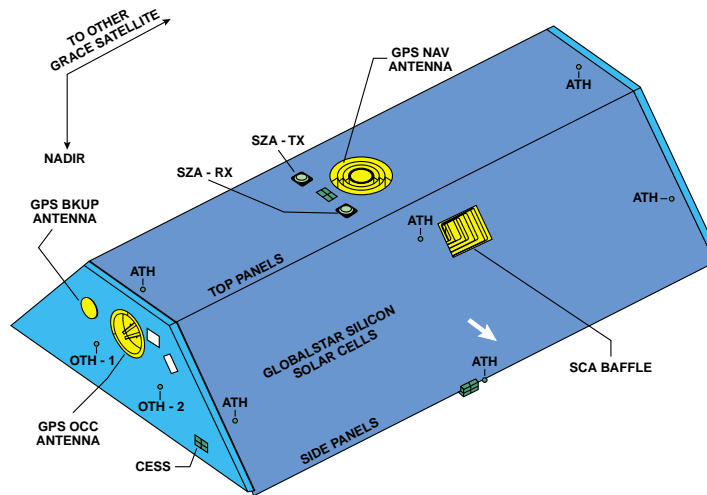
Science Data System (SDS). The SDS functions include science data processing, distribution, archiving and product verification. The SDS is a distributed entity and managed in a cooperative approach by JPL and University of Texas Center for Space Research (UTCSR) in the U.S. and GeoForschungszentrum Potsdam (GFZ) in Germany. The cooperative approach includes sharing of processing tasks, harmonization of product archives and validation/ comparison of products. Data and products to be processed and archived by the SDS include corrected intersatellite range and accelerometer measurements, GPS orbit and occultation data, orbit, gravity field and GPS occultation products. The SDS also receives, processes and archives ancillary data (e.g., meteorological fields) necessary for data processing and verification.

## **Management**

GRACE is a joint partnership between the National Aeronautics and Space Administration in the United States and DLR in Germany. The Principal Investigator is from UTCSR and the Co-Principal Investigator is from the GFZ. JPL has responsibility for the Project Management and Project Science of GRACE. Goddard Space Flight Center maintains responsibility for Mission Management.

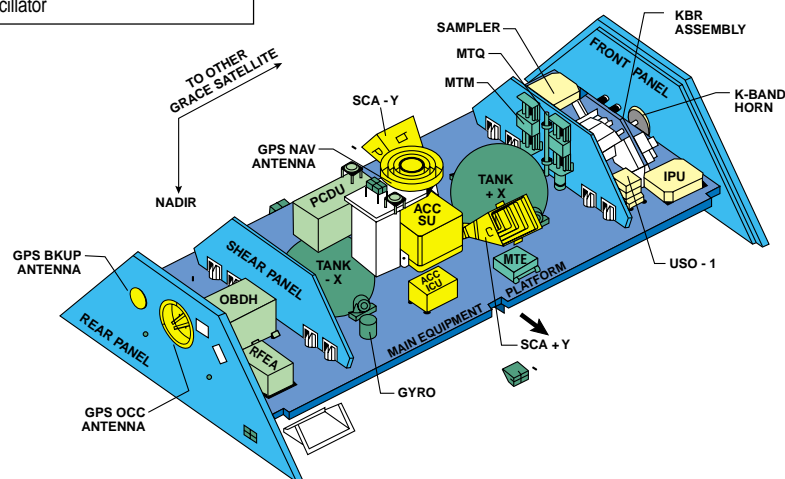
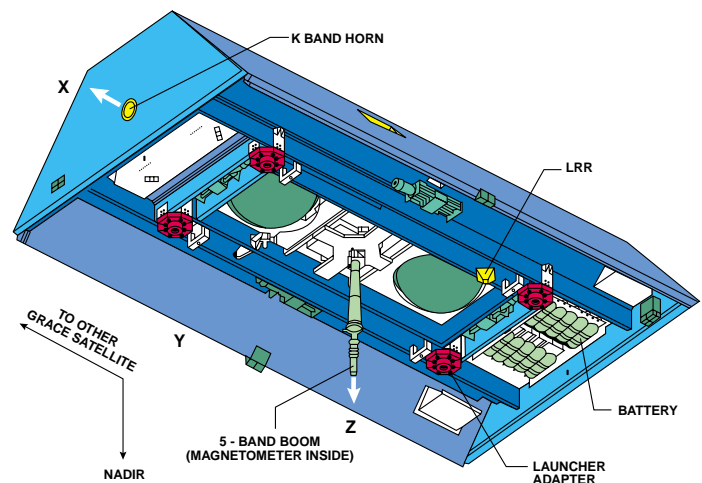
## **The Future**

GRACE builds on the heritage of GFZ's CHAMP mission in the area of Earth gravity field measurements. The revolutionary new configuration for GRACE—utilizing two satellites following one another on the same orbital track—is expected to improve the accuracy of gravity field measurements dramatically. GFZ plans another mission called GIGOLO (Gravity Information Over Land and Ocean) as a follow-on to GRACE.



### Abbreviations Used in GRACE Satellite Diagrams

ACC ICU	Superstar Accelerometer Interface Control Unit
ACC SU	Superstar Accelerometer Sensor Unit
ATH	Attitude Control Thrusters
CESS	Coarse Earth and Sun Sensor
GPS BKUP Antenna	GPS Backup Antenna
GPS NAV Antenna	GPS Navigational Antenna
GPS OCC Antenna	GPS Occultation Antenna
IPU	Instrument Processing Unit
KBR Assembly	K-Band Ranging System Assembly
LRR	Laser Retro Reflective Assembly
MTE	Center of Mass Trim Assembly Electronics
MTM	Center of Mass Trim Assembly Mechanism
MTQ	Magnetorquers
OBDR	On Board Data Handling
OTH-1, OTH-2	Orbit Control Thrusters
PCDU	Power Control and Distribution Unit
RFEA	Radio Frequency Electronics Assembly
SCA Baffle	Star Camera Assembly Baffle
SCA +Y, SCA -Y	Star Camera Assembly
SZA - RX	S-Band Zenith Antenna, Receive
SZA - TX	S-Band Zenith Antenna, Transmit
Tank -X, Tank +X	Cold Gas Tanks
USO-1	Ultra Stable Oscillator



Three drawings of the GRACE spacecraft are shown here. Each is a different view: from above, from below and from above with the solar panels removed. These drawings identify many of the key spacecraft components described on page 4 and depicted in the photos on the same page.